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A method of estimating whelk pot capture field area by means of an experimental ground line

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INTRODUCTION

The rational management of a harvested population of any species presupposes a stock of basic information, including, at a minimum, quantities landed, harvesting effort and population size. This article is concerned with the third of these items. A method of estimating the density of a target species harvested by means of baited traps is described. The example selected is the whelk (Buccinum undatum, L.) fishery of the west coast of the Cotentin peninsula in the western sector of the English Channel.

As a rule, pots and traps are not regarded as quantitative sampling devices, since it is difficult to relate the number of specimens caught to a known area. One of the earliest attempts to overcome this drawback was made by Miller (1975), who used underwater photography to arrive at an indirect estimate of the capture field areas of snow crab (Chionoecetes opilio) traps. More recently, Ito et al. (1981) suggested that it might be feasible to estimate the area subject to the influence of the bait (the gathering area, to use their own term) by releasing marked gastropods (specimens of Neptunea arthritica whose shells had been painted) at known distances from the trap immersion point. The findings reported by these authors should be used with caution, however, because of, inter alia, the stress to which their experimental specimens were subjected and the length of time that elapsed between the beginning of the experiment and the conclusion of trap lifting operations (13 days).

Eggers et al. (1982) adopted what we regarded as a more promising approach: they postulated that a trap (or a hook on a ground line) exerted its attraction on the bottom-dwelling creatures located within a circular perimeter, in which case the problem would be to estimate the radius of the circle in question. The protocol described below is based on that key idea.

MATERIALS AND METHODS

The object of this study was to estimate the effective surface area covered by the attraction plume of a baited trap under the ordinary working conditions of the fishery. This context subjected us to two constraints as regards:

- selection of gear: the local operators use whelk pots containing two types of bait (crab and fish);
- soak time: as a rule, ground lines are left in place for 24 hours, although on rare occasions they are left down for 48 hours or longer (Santarelli-Chaurand, 1985); that is, soak time is at least two M_2 tidal current periods. In the Channel Islands region, the propagation of the tidal currents, which is associated with rising water levels in the bays, creates a periodic circulation the alternating character of which becomes progressively more strongly marked with decreasing distance from the shore (see Fig. 1; see also Figs. 12 to 14 in Pingree et al., 1985).

Selection of model

Range of the chemical influence of a whelk pot

The geometry of the area swept by the attraction plume is determined by the preferential orientation of the back-and-forth movement of the water mass that is induced by the tide. In the case of an isolated trap set in perfectly

still water, the horizontal turbulent diffusion of the attractive molecules emitted by the bait produces on the bottom, assuming the bottom to be flat, a circular surface the perimeter of which is defined by a specified level of concentration. In water characterized by movement of constant direction and speed, the attraction plume is elongated in the direction of the set of the current (Okubo, 1980); if the movement is rotary rather than directionally constant, the plume will have swept a circular area after one complete cycle. In the Channel Islands region, the orientation of the advective process engendered by the tide changes simultaneously with its speed (see Fig. 1); the resulting movement also displays a pronounced alternating character. The area subjected to the attractive effect of a whelk pot during one M_2 period is elongated in the direction of the strongest currents, and consequently cannot be treated as a circular surface as in the model developed by Eggers et al. (op. cit.). Here we introduce our first assumption: that the perimeter of a whelk pot's gathering area is describable as an ellipse.

Up to this point, then, we have defined only a plausible model of the shape of a baited whelk pot's area of chemical influence, as determined by the physical phenomena of advection and dispersion. The border of that area, for its part, is defined by the chemosensitivity threshold of the whelk's osphradium. While attempts to detect the activity of the afferent osphradial nerves have been unsuccessful (Bailey and Laverack, 1963), it is now generally agreed that the osphradium is essentially a chemoreceptor. The whelk, furthermore, possesses a more highly developed osphradium than any other mollusk (Bailey and Benjamin, 1968). It is located in a furrow in the pallial cavity that serves to channel the incurrent siphonal flow, and this arrangement, combined with the mobility of the siphon, endows the whelk with directional chemosensitivity (Wells, 1968).

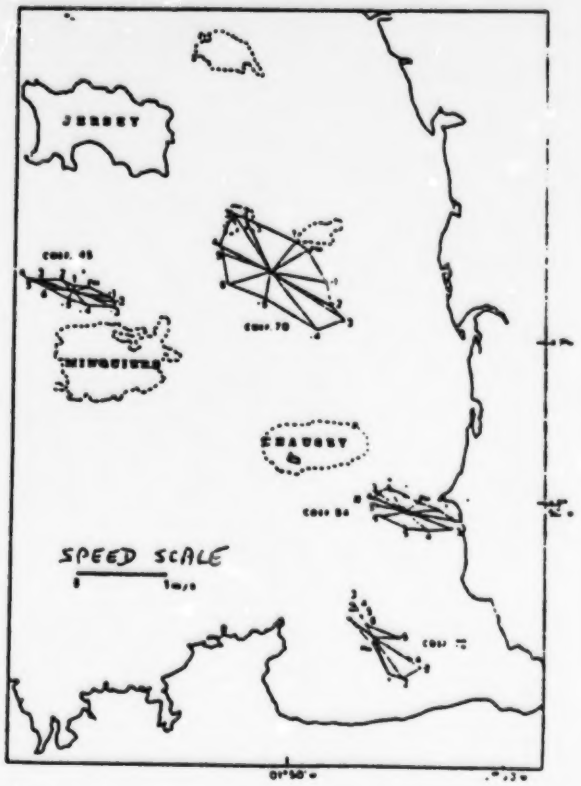


Figure 1
Courants de marée dans le golfe normano-breton (Manche Ouest) et localisation (*) de la filière expérimentale.
M_2 tidal currents in the Channel Isles region and location of the experimental ground (*).

Effective capture field of a whelk pot

At present we do not know what attractive molecule concentration level constitutes the stimulation threshold for the whelk's osphradial nerves (vide supra), and consequently we cannot determine the range of the attraction plume of a baited whelk pot. In this study, however, the problem with which we are concerned is not so much the determination of the area subject to the chemical influence of the pot as the determination of the pot's effective capture field, namely the area within which every whelk present can detect the bait for a sufficient period of time to enable it to travel to the place where the bait is located. In order to estimate the size of this area, we must make a second assumption at this point: that the effective capture field is included within the

area of chemical influence. The point is that in view of the ethology of the whelk, the sensitivity of its chemoreceptors is not really the limiting factor for our purposes, and consequently we must admit that the effective capture field is included in the area of chemical influence. A whelk advances over the substrate by means of contraction waves in its foot, and its speed of movement has been assessed in two different ways:

- very approximately, by direct observation with an underwater cinecamera placed near a pot. It has been demonstrated that whelks react immediately to the presence of bait, toward which they proceed unswervingly against the current. The maximum speed that has been estimated by means of this technique for the largest specimens (i.e. those with shells approximately 66 mm high) is 20 $cm.mn^{-1}$;
- by measurements made in the laboratory on a group of 35 whelks ranging in size between 20 and 80 mm that had been collected in the harvesting area in January 1985. These specimens were kept fasting at a water temperature of 6-9°C and then attracted with a mixture of crab and fish. They were found to advance over sand at a speed V equal to:

$$V\ (cm.mn^{-1}) = 0.083\ H(mm) + 5.82,$$

in which H designates the height of the shell. Whelks of the average size caught in the fishery (H = 50 mm) would thus move at a speed of the order of 10 $cm.mn^{-1}$.

Experimental protocol

The standard ground line used in the whelk fishery of the Channel Islands region is rigged with 50 to 60 whelk pots, which are attached to the line at 12-metre intervals. Under the terms of an agreement among the various occupational groups involved (draggermen, trawlermen and whelk fishermen), ground lines are always set running north and south, to avoid the danger of their becoming entangled either with other ground lines or with other types of fishing gear.

The experimental ground line used in this study was oriented in the same way, namely approximately 70° from the major axis of the tidal current ellipse. If we postulate that the effective capture field is elliptical in shape and that the major axis of the ellipse in question makes a uniform 70° angle with the ground line, we are confronted with the problem of how to estimate the lengths of the axes of that ellipse. This issue was resolved by studying variations in catch per pot correlated with variations in the distances separating each pot from its two immediate neighbours.

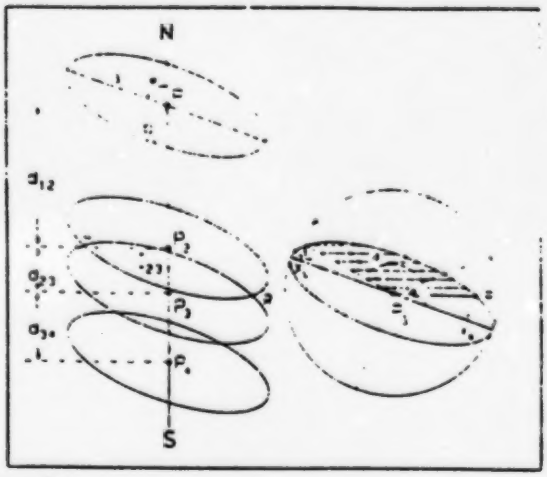


Figure 2

Modèle des aires de capture effective des casiers de la filière expérimentale, et définition des notations utilisées dans le texte. L'angle Φ est celui que forment l'axe majeur de l'ellipse des courants de marée avec la direction nord-sud de la filière. Sur le schéma de droite sont précisés les éléments intervenant dans le calcul de la surface d'intersection I_{23} : l'aire A du secteur d'ellipse y est identifiée par des hachures (*voir* texte).

Left: model of the geometry of the elliptical capture fields of four whelk-pots, P_1, ..., P_4 from the experimental ground line; Φ is the angle between the line and the major axis of the M_2 tide. Right: definition of the features used in calculating the intersection area I_{23} between two adjacent fields; hatching: area of the sector A (*see text*).

Figure 2 shows the theoretical effective capture field areas of four whelk pots (P_1, ... P_4) out of the 50 making up the experimental ground line. The whelk pot designated P_1 was isolated, and after 24 hours of soak time it contained a theoretical maximum catch C_{max} originating from the surface $\pi.a.b$ covered by the ellipse. In contrast, the capture field of the pot designated P_3 overlapped with those of the pots designated P_2 and P_4. Let I_{23} (d_{23}; a, b) and I_{34} (d_{34}; a, b) represent the overlapping areas of the capture fields of pots P_2 and P_3 and of pots P_3 and P_4 respectively. The theoretical catch $\tilde{C}_3$ of pot P_3 is equal to:

$$\tilde{C}_3 = \frac{C_{max}}{\pi ab}\left[\pi.a.b - \frac{1}{2}(I_{23}+I_{34})\right].$$

The surface areas I are calculated as follows: let A represent the area of the sector bounded by the segments P_3L, P_3R, and by the small arc LR of the ellipse surrounding pot P_3 (see Fig. 2).

$$A = a.b(\theta_L - \theta_R)/2,$$

in which the angles θ_L and θ_R, expressed in radians, are equal to:

$$\theta_L = \text{Arc}\cos(X_L/a), \qquad \theta_R = \text{Arc}\cos(X_R/a).$$

with:

$$X_{L,R} = (-k_2 \mp \sqrt{(k_2^2 - 4k_1k_3)})/(2k_1)$$

$$k_1 = \left(\frac{b^2}{a^2}\text{cotg}^2\Phi + 1\right)a^2$$

$$k_2 = -\left(\frac{b^2}{a^2}\text{cotg}^2\Phi + 1\right)\left(\frac{d_{23}\cos\Phi}{a^2}\right)$$

$$k_3 = \frac{d_{23}^2\cos^2\Phi}{2}\left(\frac{b^2}{2a^4}\text{cotg}^2\Phi + \frac{\text{tg}^2\Phi}{2b^2} + \frac{1}{a^2}\right) - 1$$

Table 1

Résultats des pêches réalisées avec la filière expérimentale les 22, 24 et 25 mai 1984. Première colonne : indice j du casier. Deuxième colonne : facteur contrôlé, distance au casier $j+1$ (exprimée en mètres). Trois dernières colonnes : valeurs observées des prises par casier C_j (en kilogrammes); les données jugées aberrantes sont entre parentheses.

Catches (kg/pot) obtained on 22, 24 and 25 May 1984 with the experimental ground line. First column: index j of the whelk-pot. Second column: controlled factor, distance (in metres) to the next pot. Last three columns: observed values of C_j (in kilograms); figures in brackets are outliers.

Index j of whelk pot	Distance to pot j + 1	Catch per pot		
		22 May	24 May	25 May
1	23.8	3.15	3.80	2.25
2	11.9	2.50	2.30	1.65
3	6.0	2.50	2.25	1.40
4	23.8	2.30	2.50	1.35
5	23.8	2.30	2.75	1.40
6	6.0	1.35	1.65	1.50
7	11.9	2.10	1.10	1.45
8	23.8	1.95	1.95	1.05
9	35.7	1.65	3.25	2.50
10	35.7	2.45	2.95	2.70
11	23.8	2.80	2.25	1.30
12	11.9	2.95	2.00	1.95
13	6.0	2.15	1.25	1.65
14	6.0	1.95	1.45	1.60
15	23.8	2.40	1.30	1.40
16	35.7	(1.65)	(2.55)	(0.95)
17	6.0	2.30	1.95	1.40
18	35.7	2.30	1.65	1.20
19	6.0	1.80	2.05	1.60
20	11.9	1.75	2.15	1.00
21	6.0	1.80	2.20	1.15
22	31.5	1.30	2.40	1.65
23	35.7	3.55	2.65	2.05
24	11.9	1.60	2.85	1.25
25	35.7	2.35	2.80	1.75
26	11.9	1.55	(1.15)	1.95
27	23.8	1.75	2.60	1.90
28	35.7	2.10	2.85	1.20
29	23.8	2.65	3.05	1.65
30	23.8	2.00	3.00	1.85
31	23.8	2.20	3.15	2.15
32	23.8	2.60	3.10	2.25
33	11.9	2.60	2.60	2.55
34	23.8	2.10	2.45	2.30
35	35.7	2.00	2.85	3.35
36	23.8	0.40	3.35	(1.35)
37	6.0	2.60	2.45	1.65
38	6.0	0.70	2.85	2.60
39	11.9	1.15	2.10	2.30
40	35.7	1.45	2.85	3.15
41	6.0	2.00	3.90	2.65
42	35.7	1.45	3.35	2.30
43	11.9	1.70	2.85	2.75
44	11.9	1.75	2.25	2.20
45	6.0	1.75	3.25	1.65
46	11.9	1.65	3.10	1.85
47	6.0	1.60	3.65	2.05
48	6.0	1.45	2.75	2.05
49	11.9	1.70	2.75	2.05
50	–	1.05	2.60	2.45

The area of triangle P_3LR is then subtracted from that of area A, producing the value of $I_{23}/2$.

In the definition of surface areas I, the controlled factor is the distance between pots d (see Fig. 2). A range of four values (6, 11.9, 23.8 and 35.7 m) was selected in advance for purposes of attaching the whelk pots to the ground line (see Table 1). The second of these values, 11.9 m, is the one ordinarly adopted in the fishery. The fully rigged line was 935 m long. In order to avoid any bias that might be caused by local variations in whelk density, the distances between pots were randomly distributed along the line (see Table 1).

The experiments were conducted at a point approximately four miles off Granville, at latitude 48°50' N and longitude 1°43' W (see Fig. 1). The ground line was set three times, on 22, 24 and 25 May 1984, in a period of neap-tides (coefficient 40), and was left down for 24 hours each time.

Optimality criterion and identification of parameters

Let P_i, P_j and P_k represent three consecutive whelk-pots ($i = 1,2 \ldots 48$; $k = 3,4 \ldots 50$), and let $\tilde{C}_j$ represent the theoretical catch obtained with pot j. We know from the foregoing that:

$$\tilde{C}_j = \psi(d_{ij}, d_{jk}; a, b, C_{max})$$

When the ground line is lifted, a catch C_j is observed in the j^{th} pot. The three parameters a (semimajor axis), b (semiminor axis) and C_{max} (catch obtained with an isolated pot) are identified by minimizing the total quadratic disparity S between the observed catch C_j and the theoretical catch $\tilde{C}_j$:

$$S(a, b, C_{max}) = \sum_{j=1}^{50} (C_j - \tilde{C}_j)^2.$$

The optimal values a^*, b^*, C^*_{max} that were used to calculate the area of the pot's effective capture field and to estimate whelk density thus now serve to verify:

$$S(a^*, b^*, C^*_{max}) = min\left\{s(a, b, C_{max})\right\}$$

The minimum of the desired function S was attained by means of a direct exploration algorithm (the Simplex method devised by Neldor and Mead, 1965). To determine how accurately the parameters had been estimated, the jackknife technique (cf. Efron, 1982) was used, in its most usual form; that is, a pseudo-value was calculated for each observation C_j. We should note at this point that the Quenouille-Tukey standard errors obtained by this means presuppose simple random sampling of the observations. In point of fact, for the purposes of this study the whelk pots were not placed at random on the whelk beds; it was only the distances between pots that were randomized. A truly rigorous interpretation of the estimated sampling error values obtained in this way would present difficulties. None the less, those values do afford a means of assessing the degree of confidence that can be placed in the findings; furthermore, the jackknife is an effective means of detecting aberrant values (Huber, 1972).

RESULTS

The results we obtained when we fitted the model to the actual catches C_j are shown in Fig. 3a, b and c.

Residuals of the least-squares fit for the catches observed on 22 May 1984 are shown in Fig. 3a (upper graph). The abscissa scale represents the physical positions of the whelk pots on the ground line and shows the randomization of the four values selected for the distance between pots. The residuals $C_j - \widetilde{C}_j$

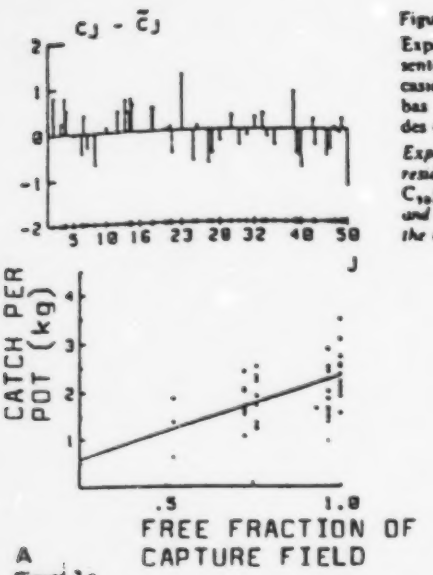


Figure 3a

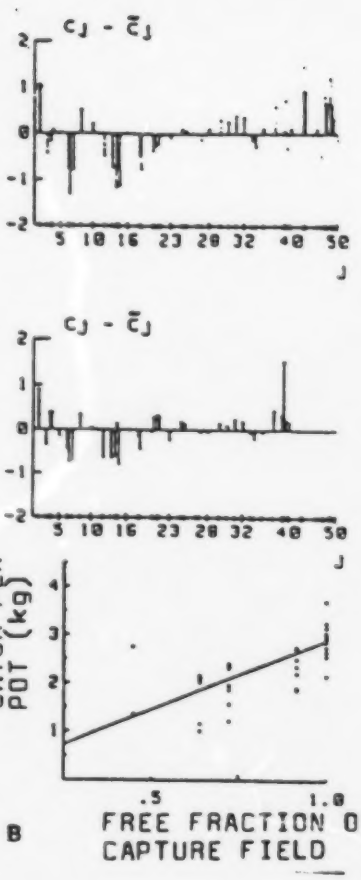
Expérience du 22 mai 1984. Graphe supérieur, échelle des abscisses : positions relatives des casiers de la filière expérimentale ($j = 1, ..., 50$); ordonnées : écarts à l'ajustement. Graphe inférieur : variations de la capture par casier en fonction de la proportion de la surface de pêche non soumise à l'influence des casiers adjacents.

Experiment of 22 May 1984. Upper graph, abscissa scale: relative positions of the whelk-pots on the ground line, showing the randomization of the four selected values of between-pots distances. Ordinates: differences between observed and expected catches per pot (in kilograms). Lower graph: Variations of catches per pot as a function of the non-overlapping proportion of the capture field.

Figure 3b

Expérience du 24 mai 1984. Le graphe du haut représente les écarts à l'ajustement pour l'ensemble des casiers de la filière. Le graphe du milieu et celui du bas illustrent les résultats obtenus après élimination des captures C_{41} à C_{50}.

Experiment of 24 May 1984. Upper graph: plot of residuals of the LS fit to the whole data set $C_1, ..., C_{50}$) of the theoretical relation between catch per pot and pot spacing. Two lower graphs: results of fitting the model to the observed catches $C_{41}, ..., C_{50}$.



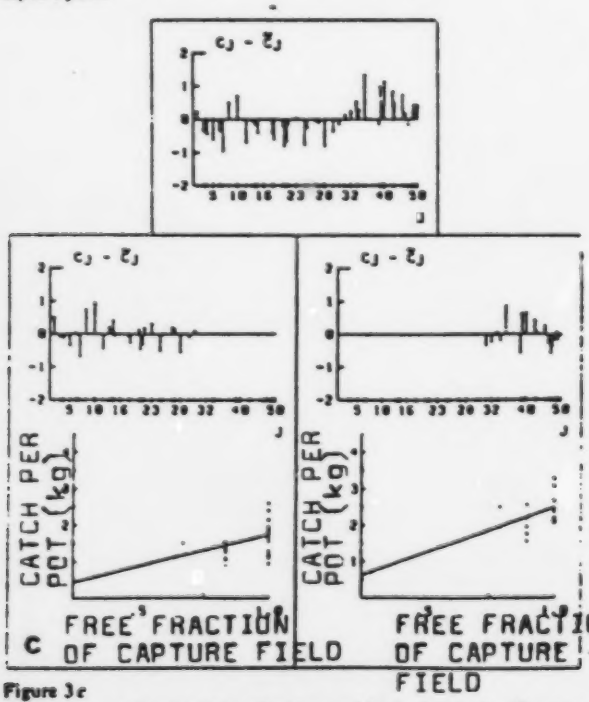


Figure 3c

Expérience du 25 mai 1984. Graphe supérieur : écarts $C_j - \bar{C}_j$ pour $j = 1, ..., 50$. Graphes médians et inférieurs : résultats de l'ajustement du modèle aux captures C_1 à C_{30} (à gauche), et C_{31} à C_{50} (à droite).

Experiment of 25 May 1984. Upper graph: plot of residuals of the fit to the whole data set $C_1, ..., C_{50}$. Lower graphs: results of fitting the model to observed catches $C_1, ..., C_{30}$ (left), and $C_{31}, ..., C_{50}$ (right).

Table 2

Résultats de l'ajustement aux captures par casier de la filière expérimentale. Lignes 1 à 3 : valeurs optimales a^*, b^* et C^*_{max} des paramètres du modèle, et erreurs-standard (entre parenthèses) estimées par la technique du jackknife. Ligne 4 : surface de capture effective (estimée) d'un casier. Ligne 5 : estimations de la densité des buccins.

Results of the fit of the capture field model to data obtained on 22, 24 and 25 May 1984. First three rows: LS parameter estimates (with Quenouille-Tukey standard errors in brackets) of semimajor and semiminor axes a^* and b^* (in metres), and of C^*_{max} catch of an isolated pot (in kilograms). 4th row: estimated area (m^2) of the capture field of the whelk-pot. 5th row: whelk density estimates (individuals.m^{-2}).

	22 May	24 May	25 May	
	$C_1 - C_{50}$	$C_1 - C_{40}$	$C_1 - C_{30}$	$C_{31} - C_{50}$
a^* (m)	17.54 (5.93)	20.40 (3.55)	19.57 (5.76)	17.90 (4.23)
b^* (m)	6.65 (3.79)	7.80 (1.26)	5.00 (2.19)	4.13 (0.90)
C^*_{max} (kg)	2.34 (0.33)	2.90 (0.11)	1.75 (0.14)	2.49 (0.14)
Effective capture field of pot (m^2)	366.4 (258.3)	500.1 (89.4)	307.2 (86.9)	232.3 (64.0)
Density of whelks (individuals/m^2)	0.351 (0.247)	0.349 (0.062)	0.313 (0.150)	0.590 (0.159)

display no structured trend. Two pots that had rolled over on the bottom (Nos. 16 and 36) and yielded aberrant values (see Table 10) were eliminated. Variations in catch per pot, correlated with the percentage of the effective capture field not contaminated by the adjacent pots, are shown in Fig. 3a (lower graph). The optimal values a^*, b^* and C^*_{max} are listed in the first column in Table 2.

In the experiments conducted on 24 and 25 May, whelk microdistribution phenomena complicated the task of identifying the parameters. For example, the residuals of the least-squares fit of the model to total catches obtained on 24 May (see Fig. 3b, upper graph) display a clear-cut spatial trend. In addition, nearly all of the last ten pots contained the maximum catch (C_{41} - C_{50}, see Table 1, second column), regardless of their differential spacing vis-à-vis their immediate neighbours. This is interpreted as the result of the end (the last 100 m or so) of the ground line's having been placed in a high-density patch in the whelk bed. Accordingly, the catch values obtained with the last ten pots, which provided no information on parameters a and b, were omitted from the fitting operation (see Fig. 3b, middle graph). The results obtained by applying the model to the series of observations C_1 ... C_{50} are shown in Fig. 3b (lower graph); the corresponding numerical values are listed in the second column in Table 2. While the catch values C_{41} ... C_{50} were not used for purposes of the fitting operation, they were, of course, used to estimate the abundance of the whelk population.

Local variations (on a one-kilometre scale) in whelk density also made it necessary to segment the series C_j observed on 25 May: the residuals of the least-squares fit to the whole data set (see Fig. 3c, upper graph) show an increase in catch values beginning with whelk pot No. 30. In contrast to the previous case, however, the quantities involves were never so great as to

mask the effect of distance between pots on catch values. The parameters a, b and C_{max} were thus identified by fitting the model to the series C_1, ... C_{30} on the one hand, and to the series C_{31}, ... C_{50} on the other (see Fig. 3c, middle and lower graphs at left and right respectively; Table 2, third and fourth columns).

DISCUSSION AND CONCLUSION

To begin with, we should recall at this point that the definition of the geometric model of the capture field is based on two assumptions, namely:
- that the detectability boundary of the bait is elliptical in shape, and
- that a pot's effective capture field is included within the area of its chemical influence.

Plausible though the first of these assumptions may be, suggested as it was by direct knowledge of the hydrology of the area where the experiments were conducted, the fact remains that it is too schematic to account satisfactorily for the complex interactions among whelk pots on a single ground line; for example, two neighbouring pots act synergistically on whelks at a distance, owing to the fact that their respective attraction plumes are mutually reinforcing, but they enter progressively into competition with each other as the whelks approach. The second assumption is undoubtedly true for the soak time used in this series of experiments (24 hours), but might not be true for a longer period: in theory, if the attractive power of the bait remained constant, the effective capture field area would tend to merge with the area of chemical influence as soak time lengthened. In addition, there are a number of phenomena that would come decisively into play with prolonged immersion. Chief among these are:
- escapement, the incidence of which was quantified by Munro (1974) for bow nets left on the bottom for up to two weeks;

- saturation of the trap, which depends not only on the behaviour of the target species, in particular its ability to escape from the trap, but also on the characteristics of the trap itself and on the harvesting strategy adopted (Miller, 1979);
- the possible in-migration of specimens that are initially located beyond the range of the attraction plume but encounter it in the course of their travels;
- attenuation of the effluvia emitted by the bait and consumption of the bait by the specimens in the trap.

These problems, which become critical in fisheries where traps remain on the bottom for several days, suggest that it would be desirable to design experiments aimed at identifying the components of the multifactorial variability in catch per pot (Miuller, 1983). Their impact was regarded as minor in the case of this study, devoted as it was to a fishery in which the ground lines are lifted on virtually a daily basis (Santarelli-Chaurand, 1985) and in which the target species is a slow-moving gastropod. This enabled us to estimate the capture field areas of the pots. On the other hand, our findings can be regarded as valid only within the framework of our experimental protocol; in particular, they are valid only given a soak time of 24 hours and bait of a specific type (the type most commonly used in the whelk fishery of the Channel Islands region).

In this context, which reflects the standard practice of the industry, the optimal values a^* and b^* as determined from the three experiments appear to be mutually consistent. Furthermore, the ratios b^*/a^* are compatible with the value for the ellipticity of the tidal currents in the experimental area yielded by the model developed by Pingree et al. (1985), namely between 20% and 40%. Lastly, if the whelks move toward the pot at an average speed of 6 $m.h^{-1}$ (vide supra) and are inside the attraction plume for three to four hours

while the current is setting in either a west-northwesterly or an east-southeasterly direction (see Fig. 1), they may traverse a distance exactly equal to the length a^* of the semimajor axis of the ellipse.

The area of a whelk pot's effective capture field thus averages 375.5 m^2 (standard error: 98.2 m^2). The variability probably originates from the simplicity of the model selected: over and above the fact that the ellipse constitutes only an approximation to the capture field, it is not clear that the catching power of the ground line is equivalent to the sum of the catching power of the individual traps. The possibility of synergism was not taken into account. Variations in the theoretical maximum catch C_{max} (from 1.75 to 2.90 kg, but in all cases less than the maximum capacity of the whelk pot) are to be attributed essentially to spatial heterogeneity in the distribution of the whelks. As it had previously been determined that 1 kg of whelks consisted of 55 specimens, the mean numerical density of the whelk population in the area where the experiment was conducted was estimated at 0.374 specimens.m^{-2} (standard error: 0.098 specimens.m^{-2}). It is difficult to assess the validity of this estimated value by comparing it with the findings of other investigators, as few references are available. At best we may note that our figure is of the same order of magnitude as those found by Petersen (1911) for Danish waters and by Holme (1966) for the English Channel. There are two possible sources of inaccuracy none the less:

- If we admit that the factor which determines the limit of the range of the attraction plume is the whelk's ability to travel, then, since we know that the larger the specimen the greater its ability to travel, large whelks must necessarily be more vulnerable than small ones. It follows that the effective capture field is smaller for the latter than for the former, and that the catch per pot gives us a distorted picture of the demographic structure of the whelks that detect the bait.

- For practical reasons, the experiments were conducted during a period when the tidal amplitude was relatively small. It would seem a priori that while variations in this factor might affect the area of chemical influence, they would be unlikely to affect the size of the effective capture field if the speed of the tidal current did not retard the rate of movement of the whelks (which advance toward the bait against the current). However, this point deserves further investigation.

In this connection, we may note that the proposed experimental design could be improved upon in some respects:

- adoption of a larger range of variation for the controlled factor (the spacing between whelk pots), especially toward the low-value end. Analysis of our data revealed that the proportion of any given pot's capture field which was not subject to contamination from the two adjacent pots was always greater than 50% and in most instances greater than 75% (see Fig. 3a, b and c). This finding shows that the men who work the fishery have arrived empirically at a good practical compromise between ground-line efficiency (with a 12-metre interval between pots coverage is approximately 10%) and the constraints associated with handling and cost;
- placement of a current meter on the experimental ground line with a view to, inter alia, arriving at a more accurate determination of the orientation of the major axis of the oscillating current with the period M_2;
- examination of the stability of the findings when the pots are left on the bottom for only one M_2 period instead of two. In that case the theoretical catch $\widetilde{C_3}$ of whelk pot P_3 (see Fig. 2) would be calculated as follows:

$$\widetilde{C}_3 = [1 - l_{23}/(\pi . a . b)]$$

or as follows:

$$\widetilde{C}_3 = [1 - l_{34}/(\pi . a . b)].$$

The question of which of these expressions would be preferable would depend on the time when the ground line was set and on the direction of rotation of the current. In this study, soak time was 24 hours. Consequently, neither of the above formulas was suitable for calculating $\widetilde{C}_3$, and we decided to count as part of every pot's effective capture field half of the area of overlap with the capture field of each of the two adjacent pots (with the range of distances between pots that we used, these areas of overlap never involved more than two ellipses).

While the method we used lacked these refinements, it did yield findings that demonstrate the feasibility of taking quantitative samples of vagile benthic macrofauna by means of a fixed type of catching gear associated with an organic attractant. The option selected in this case was the identification of parameters that could be used to calculate capture fields by controlling variations in their areas of overlap; consequently, it was necessary to use a number of traps simultaneously. This is not always feasible, especially when it involves setting costly gear in deep water; it is for that reason that abyssal epibenthos density is estimated by methods involving the use of free-standing baited traps (Desbruyères et al., 1985). In defining the area swept by the effluvia from the bait, those investigators used a numerical model of advection and dispersion around the source to describe the attraction plume. It is worth noting that these two approaches are by no means incompatible and could well be applied simultaneously. Whether used together or separately, however, they constitute a method that is likely to prove particularly useful where because of the nature of the substrate and/or the ethology of the target species it is impractical to use other sampling techniques such as dredging or trawling.

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